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**Research Paper**

# Enhancing rice – rice system productivity through site-specific nutrient management using decision support tools

SUKANTA PAL[1], MEGHA SANA[2], HIRAK BANERJEE[3], JAGAMOHAN NAYAK[4], SANGITA BANERJEE[5] AND RONITA SARKAR[6]

*Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, West Bengal 741252, India*

## ABSTRACT

The use of decision support tools (DST) for capturing the site-specific information is important for developing NPK recommendation. To understand the performance of rice (*Oryza sativa* L.) under different fertilizer management practices based on DST under rice – rice cropping system, a researcher-managed trial (*kharif* 2019 to *boro* 2020-21) was conducted at Regional Research Sub-Station (NAZ), BCKV, Chakdaha, West Bengal. Application of $SSNM_{NE}$ significantly increased all measured growth parameters and yield components of rice over other treatments in all the four seasons. The same treatment also resulted in significantly higher seed and straw yield (16.67 and 2.42% more than the values in FFP treatment respectively in *kharif* season, while 8.51 and 0.45% more than the values in FFP treatment respectively in *boro* season). System production efficiency was also highest with $SSNM_{NE}$. Net return, B:C ratio and system economic efficiency were also highest with $SSNM_{NE}$ treatment. The NR and B:C ratio obtained in $SSNM_{NE}$ treatment were 30.7% and 17% higher than that of FFP treatment respectively in *kharif* season, while 13.6% and 12.1% higher than that of FFP treatment respectively in *boro* season. The SEE obtained in $SSNM_{NE}$ treatment was also 18.5% higher than that of FFP treatment. Hence, superiority of $SSNM_{NE}$ treatment was proved over others in augmenting rice – rice system productivity in lower Gangetic plains of West Bengal.

***Key words:*** Decision Support Tool, Leaf Colour Chart, Nutrient Expert, Rice, Site Specific Nutrient Management

In India, the state of West Bengal has the largest rice production of 15.5 million tonnes from an area of 5.80 million ha (FAOSTAT, 2018). Still the demand for rice continues to increase owing to continued population growth. During past 10 years, rice yields have shown declining or stagnant trends in most rice growing areas of the state (Mondal *et al.,* 2012). Hence, West Bengal has to increase its present level of rice productivity (2.79 t/ha) by a significant level in future.

Rice yield depends not only upon genetic characteristics but also the agronomic practices (Maiti *et al.,* 2007). Inputs of NPK fertilizer represent a major proportion of rice production cost. The average NPK application rates per unit area for rice production in West Bengal is greater than other rice growing states. But, the over use of NPK fertilizer leads to low nutrient use efficiency (NUE) and rapid nutrient loss and may decrease yield and economic benefit making rice more susceptible to lodging, pests and diseases (Pal *et al.,* 2008).

Hence, the nutrient management for rice requires an approach that enables adjustments in NPK applications to accommodate the field as well as season-specific needs of the crop. Therefore, site-specific nutrient management (SSNM) is the only option left with us to ensure that NPK are provided in optimal amounts in readily available form during crop growth period (Pal *et al.,* 2008). The SSNM aims at dynamic field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their variation in time and space. The crops' need for NPK fertilizer are determined from the gap between the supply of a nutrient from indigenous sources, as measured with a nutrient omission plot, and the demand of the rice crop for that nutrient, as estimated from the total nutrient required by the crop to achieve a yield target for average climatic conditions. The SSNM avoids indiscriminate use of nutrients by preventing excessive and or inadequate nutrient inputs, and ultimately reduced the fertilizer cost.

A great challenge in SSNM is to develop quantitative yet simple method to estimate site-specific optimum NPK rates to meet crop needs (Cui *et al*., 2008). The present study used decision support tools for capturing the site-

[1]**Corresponding author's Email:** jaganayak532@gmail.com
[1,3]Professor, [2,4]Ph.D Scholar, [5,6]M.Sc Student, Department of Agronomy, BCKV, Mohanpur, Nadia, West Bengal 741 252, India

specific information that is important for developing NPK recommendation. Nutrient Expert (NE) is a computer-based decision support tool having nutrient decision support software that uses the principles of SSNM and enables to develop fertilizer recommendations tailored to a specific field or growing environment (Mitra *et al.*, 2019). The parameters needed in SSNM are usually measured in nutrient omission trials. With NE, parameters can be estimated using proxy information, which allows to develop location-specific fertilizer guidelines without data from field trials. The optimum use of NPK can be achieved by matching NPK supply with crop demand. A simple and quick method for estimating plant N demand is leaf color chart (LCC). This hand-held portable device is easy to use and an inexpensive diagnostic tool for monitoring the relative greenness of rice leaf as an indicator for the plant N status and can be used as an alternative to chlorophyll meter. Use of LCC for precision N management has consistently increased grain yield and profit in comparison to the farmers' fertilizer practice in West Bengal. With this background, in the present study we hypothesize that applying nutrients on a site-specific basis using the fertilizer decision support tools may improve the rice productivity in the lower Gangetic plains of West Bengal.

## MATERIALS AND METHODS

A fixed experiment was conducted at Regional Research Sub-Station (NAZ), Bidhan Chandra Krishi Viswavidyalaya, Chakdaha, West Bengal (23°5.3′N latitude; 83°5.3′E longitude; 9.75 m above MSL) during *kharif* 2019 to *boro* 2020–21. The location had a sub-tropical climate with moderately cool winter. The soil of the experimental field was silty clay (sand 13.52%; silt 38%; clay 48.48%) in texture with pH = 7.51, electrical conductivity (EC) = 0.61 dS/m, organic carbon = 0.65%, available N = 185 kg/ha, available P = 16 kg/ha and available K = 137 kg/ha. The rice variety 'Satabdi (IET 4786)', an *indica-japonica* high yielding variety (CR 10-114 × CR 10-115), was used in this experiment.

Experiments were laid out in a randomized complete block design with eight fertilizer management treatments and three replications using individual plots size of 20 $m^2$. The detailed information of all treatments is shown in Table 1. Pre-germinated seeds were manually broadcasted onto the soil surface in a seedbed at a seed rate of 75 kg/ha with sowing dates of 25 June in *kharif* and 20 December in *boro* seasons in both years. Seedlings of 25 and 45 days old were transplanted with 3 seedlings/hill on 20 July in *kharif* and 4 February in *boro* seasons in both years at a hill spac-

**Table 1.** Detailed information of different treatments provided to rice (cv. Satabdi) in *kharif* and *boro* season

| Treatment | Treatment short form | *Kharif* season | *Boro* season | Time of application* |
|---|---|---|---|---|
| $T_1$, Recommended dose of fertilizer | RDF | 60-30-30 kg N-$P_2O_5$-$K_2O$/ha | 120-60-60 kg N-$P_2O_5$-$K_2O$/ha | Basal: 1/4 N + full $P_2O_5$ + 2/3 $K_2O$<br>1st TD: ½ N at 21 DAT<br>2nd TD: ¼ N + 1/3 $K_2O$ at 42 DAT |
| $T_2$, Site specific nutrient management based on 'Nutrient Expert' | $SSNM_{NE}$ | 50-14-21 kg N-$P_2O_5$-$K_2O$/ha | 125-39-65 kg N-$P_2O_5$-$K_2O$/ha | Basal: 1/4 N + full $P_2O_5$ + 2/3 $K_2O$<br>1st TD: ½ N at 21 DAT<br>2nd TD: ¼ N + 1/3 $K_2O$ at 42 DAT. |
| $T_3$, Site specific nutrient management based on 'Leaf Colour Chart' | $SSNM_{LCC}$ | 50-14-21 kg N-$P_2O_5$-$K_2O$/ha | 112-39-65 kg N-$P_2O_5$-$K_2O$/ha | Basal: Full $P_2O_5$ + Full $K_2O$<br>TD: ½ N each at 15 and 25 DAT in *kharif* season; ¼ N each at 14, 21, 35 and 42 DAT in *boro* season |
| $T_4$, $T_2$ – N | $SSNM_{NE}$ – N | 0-14-21 kg N-$P_2O_5$-$K_2O$/ha | 0-39-65 kg N-$P_2O_5$-$K_2O$/ha | Basal: Full $P_2O_5$ + 2/3 $K_2O$<br>TD: 1/3 $K_2O$ at 42 DAT |
| $T_5$, $T_2$ – P | $SSNM_{NE}$ – P | 50-0-21 kg N-$P_2O_5$-$K_2O$/ha | 125-0-65 kg N-$P_2O_5$-$K_2O$/ha | Basal: 1/4 N + 2/3 $K_2O$<br>1st TD: ½ N at 21 DAT<br>2nd TD: ¼ N + 1/3 $K_2O$ at 42 DAT |
| $T_6$, $T_2$ – K | $SSNM_{NE}$ – K | 50-14-0 kg N-$P_2O_5$-$K_2O$/ha | 125-39-0 kg N-$P_2O_5$-$K_2O$/ha | Basal: 1/4 N + full $P_2O_5$<br>1st TD: ½ N at 21 DAT<br>2nd TD: ¼ N at 42 DAT |
| $T_7$, Absolute control (–NPK ) | AC (–NPK) | 0-0-0 kg N-$P_2O_5$-$K_2O$/ha | 0-0-0 kg N-$P_2O_5$-$K_2O$/ha | - |
| $T_8$, Farmer fertilizer practice | FFP | 75-25-10 kg N-$P_2O_5$-$K_2O$/ha | 130-50-50 kg N-$P_2O_5$-$K_2O$/ha | Basal: 1/4 N + full $P_2O_5$ + 2/3 $K_2O$<br>1st TD: ½ N at 21 DAT<br>2nd TD: ¼ N + 1/3 $K_2O$ at 42 DAT |

TD, top dressing; DAT, days after transplanting
*Same for *kharif* and *boro* season, except treatment $T_3$

ing of 20 cm × 15 cm. Fertilizers used were urea for N, single super phosphate for P and potassium chloride for K with doses as per treatment details. N was split-applied: 25, 50 and 25% at basal, mid-tillering and panicle initiation, respectively. P was applied as basal. K was split-applied: 70 and 30% at basal and panicle initiation, respectively. During transplanting, 2-3 cm depth of water was maintained for establishment of seedling and thereafter 4-5 cm of water was maintained throughout the growing season. As the crop growth progresses, the depth of submergence was increased. To minimize seepage between plots, all bunds were raised with 0.5 m width for separating different plots. Finally, the water was driven out two weeks before harvesting. Weeds, pests and diseases were intensively controlled by chemicals to avoid yield loss. The plants were cut at the base after attaining harvest maturity (at 115 and 125 days in *kharif* and *boro* seasons, respectively). The plant samples were sun-dried for 2-3 days, and then seeds were separated.

### *Biometrical observations and economic assessment*

In each plot, third row was marked for destructive sampling as well as for recording different biometric observations. Leaf chlorophyll content was determined colorimetrically as per the DMSO (Dimethyl sulphoxide) method as suggested by Shoaf and Lium (1976). Ten panicles were randomly selected from each plot to determine 1000-grain weight and number of grains per panicle and other yield parameters. The middle two rows were marked for the determination of seed yield. Plant samples from each treatment were collected, oven dried, and ground for analyzing total recoveries of N, P and K at harvest, as per standard methods. For determination of nutrient (NPK) status of post-harvest soil, standard procedures were followed. The economic assessment in terms of net return and benefit: cost (B:C) ratio of rice cultivation was worked out on the basis of prevailing market prices of inputs and outputs.

### *Yield response to fertilizer NPK vis-a-vis indigenous nutrient supply*

Yield response is the yield difference between attainable yield (here, yield with $SSNM_{NE}$) and the nutrient limited yield, and can reflect soil indigenous nutrient supply to some extent (Xu *et al.,* 2014). Total amount of fertilizer required by a crop for an entire growing season is directly related to the anticipated crop response to fertilizer (N/P/K), and can be estimated by the following formula (Ray *et al.,* 2018).

$$YRF = GY_{SSNMNE} - GY_{OT}$$

where, YRF is yield response to fertilizer N/P/K (t/ha); $GY_{SSNMNE}$ is grain yield with NPK level based on Nutrient Expert tool (t/ha); $GY_{OT}$ is grain yield with N/P/K omissions treatments (t/ha).

The nutrient-limited yield is directly related to the supply of nutrient from indigenous (non-fertilizer) sources, which include soil, crop residues, organic inputs, rainfall, atmospheric deposition and irrigation water. The indigenous nutrient supply is defined as the total amount of a particular nutrient that is available to the crop from the soil during a cropping cycle when other nutrients are non-limiting (Witt and Dobermann, 2002), which can be determined with the omission plot technique as suggested by Ray *et al.* (2018).

$$INS = NU_{N\ omission}$$

$$INP = NU_{P\ omission}$$

$$INK = NU_{K\ omission}$$

where, INS, IPS and IKS are indigenous N, P and K supply, respectively; $NU_{N\ omission}$, $NU_{P\ omission}$, $NU_{K\ omission}$ are total N, P and K uptake by the crop with N omission ($SSNM_{NE}$ – N), P omission ($SSNM_{NE}$ – P) and K omission ($SSNM_{NE}$ – K) treatments, respectively.

### *Production efficiency and economic efficiency of rice-rice cropping system*

$$SPE = \frac{GY}{D}$$

$$SEE = \frac{NR}{D}$$

Where, SPE is system production efficiency in kg/ha/day; SEE is system economic efficiency in Rs/ha/day; GY is grain yield in kg/ha; NR is net return in Rs/ha; D is duration of cropping season.

### *Statistical analysis*

The data obtained on different growth parameters, yield components, yield, nutrient uptake and soil nutrient status were analyzed statistically by the method of analysis of variance (ANOVA) as per the procedure outlined for randomized complete block design (Gomez and Gomez, 1984). Statistical significance was tested by P-value at 0.05 level of probability and critical difference (CD) was worked out wherever the effects were significant.

## RESULTS AND DISCUSSION

### *Growth parameters of rice*

In both years, the treatment $SSNM_{NE}$ significantly increased plant height (at 90 DAT), LAI (at 60 DAT), DMA (at 90 DAT), leaf chlorophyll content (at 60 DAT), CGR (at 30-60 DAT) and number of tillers/plant (at 60 DAT) over the other treatments (0.73, 7.88, 8.24, 5.30, 2.21, 2.76% higher than the values obtained in FFP treatment respectively in *kharif* season; 4.65, 5.06, 1.57, 0.48, 2.14 and 20.22% higher than the values obtained in FFP treatment respectively in *boro* season) (Table 2). High dose of fertilizer, particularly of N, seems to favour better uptake of N by the plant, resulting in bigger canopy for heavily fertilized crop. Singha *et al.* (2004) reported that higher dry matter production might be due to greater LAI, number of tillers/m$^2$ which is associated with high photosynthetic efficiency of rice plant, leading to enhanced photosynthetic accumulation and translocation together produced higher dry matter production. The higher value of Nutrient Expert® model supported treatment during the grand phase of growth and the terminal period might have contributed to overall better performance by the respective treatments. In contrary, plants receiving FFP treatment showed poor results with respect to all growth attributing characters due to unbalanced application of nutrients (Pal *et al.,* 2008). In the present study, maximum reduction in measured growth parameters was caused due to N omission ($SSNM_{NE}$ – N) and lowest was recorded in absolute control (– NPK) treatment.

### *Yield components of rice*

The $SSNM_{NE}$ treatment showed significantly higher panicle length, panicle weight, number of panicles/m$^2$ and filled grain/panicle (1.45, 8.33, 1.48 and 2.56% higher than the values obtained in FFP treatment respectively in *kharif* season; while 3.54, 0.94, 6.53 and 8.87% higher than the values obtained in FFP treatment respectively in *boro* season) (Table 3). Test weight remains unaffected in *kharif* season and however, significantly improved by $SSNM_{NE}$ treatment (13.89% higher than the values obtained in FFP treatment). Similar kind of observation was reported by Banerjee *et al*. (2006) where he concluded that increased and balanced levels of N, P and K bring huge improvement of yield components, resulting in higher yields. In the present study, greater reduction in above yield components was caused due to N omission ($SSNM_{NE}$ – N) and lowest was recorded in absolute control (– NPK) treatment.

### *Grain yield, straw yield, system productivity and production efficiency of rice-rice cropping system*

Application of $SSNM_{NE}$ treatment resulted in significantly higher seed and straw yield (16.67 and 2.42% more than the values in FFP treatment respectively in *kharif* season; while 8.51 and 0.45% more than the values in FFP treatment respectively in *boro* season) (Table 4). System productivity of rice-rice cropping system with $SSNM_{NE}$ treatment was 12.41% higher than FFP treatment. The same treatment exerted significant influence on harvest index also, accounting 4.22 and 12.71% more than the values obtained in FFP treatment during *kharif* and *boro* season respectively. System production efficiency of rice-rice cropping system was also highest with $SSNM_{NE}$ treatment.

**Table 2.** Growth attributes of rice (cv. Satabdi) under different treatments (mean data of *Kharif* 2019 and 2020, and *Boro* 2019–20 and 2020–21)

| Treatment | Plant height (cm) at 90 DAT | | LAI at 60 DAT | | DMA (g/m$^2$) at 90 DAT | | Chlorophyll content (mg/g of fresh leaf) at 60 DAT | | CGR (g/m$^2$/day) at 30-60 DAT | | No. of tillers/m$^2$ at 60 DAT | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* |
| $T_1$, RDF | 95.7 | 103.0 | 3.32 | 3.49 | 681 | 683 | 1.40 | 1.91 | 8.56 | 10.74 | 312 | 404 |
| $T_2$, $SSNM_{NE}$ | 96.7 | 105.7 | 3.56 | 3.74 | 696 | 710 | 1.59 | 2.09 | 9.25 | 11.47 | 335 | 446 |
| $T_3$, $SSNM_{LCC}$ | 94.5 | 104.0 | 3.40 | 3.00 | 639 | 673 | 1.43 | 1.98 | 8.11 | 10.36 | 311 | 421 |
| $T_4$, $SSNM_{NE}$ – N | 84.6 | 90.5 | 2.32 | 2.50 | 491 | 604 | 1.08 | 1.53 | 7.62 | 9.67 | 287 | 314 |
| $T_5$, $SSNM_{NE}$ – P | 89.8 | 99.6 | 2.75 | 3.26 | 496 | 635 | 1.26 | 1.71 | 7.95 | 10.06 | 302 | 330 |
| $T_6$, $SSNM_{NE}$ – K | 87.3 | 104.0 | 2.91 | 3.12 | 506 | 627 | 1.21 | 1.67 | 8.01 | 10.07 | 290 | 371 |
| $T_7$, AC (–NPK) | 78.8 | 86.1 | 1.98 | 2.23 | 451 | 537 | 1.02 | 1.44 | 6.93 | 8.34 | 278 | 281 |
| $T_8$, FFP | 96.0 | 101.0 | 3.30 | 3.56 | 643 | 699 | 1.51 | 2.08 | 9.05 | 11.23 | 326 | 371 |
| SEm± | 0.3 | 1.2 | 0.19 | 0.06 | 3.27 | 2.95 | 0.02 | 0.03 | 0.08 | 0.10 | 2.05 | 6.01 |
| CD (P= 0.05) | 1.0 | 3.5 | 0.56 | 0.17 | 11.06 | 9.02 | 0.06 | 0.07 | 0.25 | 0.31 | 6.28 | 18.21 |

RDF, recommended dose of fertilizers; $SSNM_{NE}$, SSNM based on 'Nutrient Expert' recommendation; $SSNM_{LCC}$, SSNM based on leaf colour chart; AC, absolute control; FFP, farmer's fertilizer practice

LAI, leaf area index; DMA, dry matter accumulation; CGR, crop growth rate; DAT, days after transplanting

**Table 3.** Yield components of rice (cv. Satabdi) under different treatments (mean data of *Kharif* 2019 and 2020, and *Boro* 2019-20 and 2020-21)

| Treatments | Panicle length (cm) | | Panicle weight (g) | | No of panicles/m$^2$ | | Filled grains/panicle | | Test weight (g) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* |
| $T_1$, RDF | 21.04 | 23.57 | 2.64 | 3.15 | 312 | 295 | 99.3 | 152.7 | 19.3 | 19.5 |
| $T_2$, $SSNM_{NE}$ | 22.42 | 23.99 | 2.73 | 3.23 | 343 | 310 | 104.0 | 162.1 | 19.8 | 20.5 |
| $T_3$, $SSNM_{LCC}$ | 21.96 | 23.75 | 2.69 | 3.00 | 324 | 300 | 100.0 | 142.0 | 19.6 | 19.8 |
| $T_4$, $SSNM_{NE}$ – N | 18.68 | 21.28 | 2.20 | 2.51 | 298 | 279 | 83.5 | 110.7 | 18.4 | 18.7 |
| $T_5$, $SSNM_{NE}$ – P | 19.06 | 22.07 | 2.05 | 2.80 | 284 | 283 | 84.4 | 130.2 | 18.6 | 19.3 |
| $T_6$, $SSNM_{NE}$ – K | 18.98 | 22.90 | 2.10 | 2.68 | 242 | 265 | 89.2 | 125.3 | 18.7 | 19.6 |
| $T_7$, AC (–NPK) | 18.50 | 19.40 | 1.76 | 1.98 | 220 | 236 | 73.8 | 98.5 | 17.5 | 17.4 |
| $T_8$, FFP | 22.10 | 23.17 | 2.52 | 3.20 | 338 | 291 | 101.4 | 148.9 | 19.4 | 18.0 |
| SEm± | 0.36 | 0.16 | 0.060 | 0.04 | 6.09 | 2.42 | 1.9 | 2.3 | 0.9 | 0.1 |
| CD (P= 0.05) | 1.08 | 0.49 | 0.177 | 0.13 | 18.21 | 7.42 | 5.9 | 6.9 | NS | 0.3 |

RDF, recommended dose of fertilizers; $SSNM_{NE}$, SSNM based on 'Nutrient Expert' recommendation; $SSNM_{LCC}$, SSNM based on leaf colour chart; AC, absolute control; FFP, farmer's fertilizer practice
NS, non-significance at 0.05%

**Table 4.** Yield and economics of rice (cv. Satabdi) under different treatments (mean data of *Kharif* 2019 and 2020, and *Boro* 2019–20 and 2020–21)

| Treatment | Grain yield (t/ha) | | Straw yield (t/ha) | | Harvest index (%) | | Net return (Rs/ha) | | B:C ratio | | System productivity (t/ha) | SPE (kg/ha/ day) | SEE (Rs/ha/ day) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | | | |
| $T_1$, RDF | 4.60 | 4.85 | 4.98 | 5.85 | 48.00 | 42.21 | 12569 | 45088 | 1.82 | 1.72 | 9.45 | 39.4 | 240.2 |
| $T_2$, $SSNM_{NE}$ | 4.90 | 5.10 | 5.07 | 6.67 | 49.40 | 46.57 | 22247 | 49053 | 2.48 | 1.95 | 10.00 | 41.7 | 297.1 |
| $T_3$, $SSNM_{LCC}$ | 4.75 | 4.95 | 5.01 | 6.24 | 48.36 | 44.22 | 18707 | 47234 | 2.26 | 1.92 | 9.70 | 40.4 | 274.8 |
| $T_4$, $SSNM_{NE}$ – N | 3.28 | 2.80 | 3.58 | 3.65 | 31.80 | 43.44 | 6711 | 6319 | 1.47 | 1.13 | 6.08 | 25.3 | 54.3 |
| $T_5$, $SSNM_{NE}$ – P | 4.28 | 3.20 | 3.94 | 4.94 | 37.40 | 39.29 | 9333 | 15829 | 1.64 | 1.32 | 7.48 | 31.2 | 104.8 |
| $T_6$, $SSNM_{NE}$ – K | 4.34 | 3.95 | 3.72 | 5.88 | 42.50 | 40.20 | 10374 | 30715 | 1.72 | 1.62 | 8.29 | 34.5 | 171.2 |
| $T_7$, AC (–NPK) | 2.14 | 2.63 | 3.35 | 4.45 | 29.75 | 37.14 | 908 | 8817 | 1.07 | 1.19 | 4.77 | 19.9 | 40.5 |
| $T_8$, FFP | 4.20 | 4.70 | 4.95 | 6.64 | 47.40 | 41.32 | 17021 | 43174 | 2.12 | 1.74 | 8.90 | 37.1 | 250.8 |
| SEm± | 0.19 | 0.05 | 0.192 | 0.66 | 1.2 | 0.15 | - | - | - | - | 0.21 | - | - |
| CD (P= 0.05) | 0.52 | 0.16 | 0.52 | 0.17 | 3.59 | 0.47 | - | - | - | - | 0.58 | - | - |

RDF, recommended dose of fertilizers; $SSNM_{NE}$, SSNM based on 'Nutrient Expert' recommendation; $SSNM_{LCC}$, SSNM based on leaf colour chart; AC, absolute control; FFP, farmer's fertilizer practice
B:C, benefit:cost; SPE, system production efficiency; SEE, system economic efficiency

Maximization of yield in rice by resorting to 'Nutrient Expert' over existing practices has been reported by Singh *et al*. (2013), who found that the performance of SSNM consistently improves grain yield by about 10-15 per cent compared to the FFP. The increased yield in the NE® treatment was achieved through a balanced application of NPK and better timing of fertilizer application (Mandal *et al*., 2016). So, the need-based nutrient supply should be tailored to harness maximum nutrient use efficiency (NUE) of applied nutrients (Garai *et al.,* 2021). Moreover, SSNM involves the feeding of crops when they truly need. Hence, both $SSNM_{NE}$ and $SSNM_{LCC}$ treatments of the present study might have correctly determined the optimum amount and timing for essential nutrient supply to fulfil maximum yield potential of rice crop in both the seasons. In contrary, FFP treatment represents imbalanced fertilization which includes excess amount of N and less amount of P and K application; hence, the poor response was obtained in terms of system productivity. In the present study, N omission ($SSNM_{NE}$ – N) caused greater reduction in both grain and straw yield (33.06 and 29.39% less than the values obtained in $SSNM_{NE}$ treatment respectively in *kharif* season; while 45.10 and 45.28% less than the values obtained in $SSNM_{NE}$ treatment respectively in *boro* season), followed by P omission and K omission treatments. Poor seed and straw yield were recorded in plots under NPK omission (absolute control treatment).

*Yield response to fertilizer NPK and indigenous nutrient supply*

In general, the total fertilizer N/P/K required by a crop for an entire growing season is directly related to the anticipated crop response to fertilizer N/P/K, which is the difference between a yield target and yield without fertilizer N/P/K – referred to as the N/P/K limited yield (Banerjee *et al.,* 2019). In the present study, total rice yield (4.90 and 5.10 t/ha) obtained in $SSNM_{NE}$ treatment was considered as targeted yield. Nutrient-limited yields were 1.62 and 2.3 t/ha for N, 0.62 and 1.9 t/ha for P, and 0.56 and 1.15 t/ha for K in *kharif* and *boro* season, respectively (Fig. 1). This result clearly proved the fact that N is the most limiting nutrient for rice followed by P and K, as the yield response of fertilizer N was higher than P and K. Thus, it can be inferred that N omission resulted in drastic reduction in yield and profitability of tested rice cultivar.

The nutrient (N/P/K) limited yield is directly related to the supply of nutrient (N/P/K) from indigenous source. In the present study, INS, IPS and IKS were estimated as 65.3 and 84.3, 8.6 and 12.9, and 84.1 and 103.9 kg/ha in *kharif* and *boro* season, respectively (Fig. 2). The results presented here reveal that growth and biomass production could have been strongly affected by the limited indigenous N and P supply, until the nutrients (N and P) are supplied through fertilizers. On the contrary, K-supplying capacity of experimental soil was higher, which might be due to historically higher K application rate in medium-K soil. When soil indigenous nutrient supply is low, the yield response would be high (Xu *et al.,* 2014). Similarly, Liu *et al.* (2011) reported that excessive nutrient inputs which contributed to more nutrient accumulation in the soil might be the reason behind relatively high levels of nutrient supply. Therefore, high K inputs have increased the residual K in the soil over the past decades and in turn enhanced the IKS. Application of chemical fertilizer is needed to replenish this essential nutrient concentration in soil (Banerjee *et al.,* 2019), but results of the present study clearly suggests that indiscriminate use of chemical fertilizers without knowing the indigenous nutrient supplying capacity of soil may fail to fulfil the demand of crops and cause negative impacts on soil health as well.

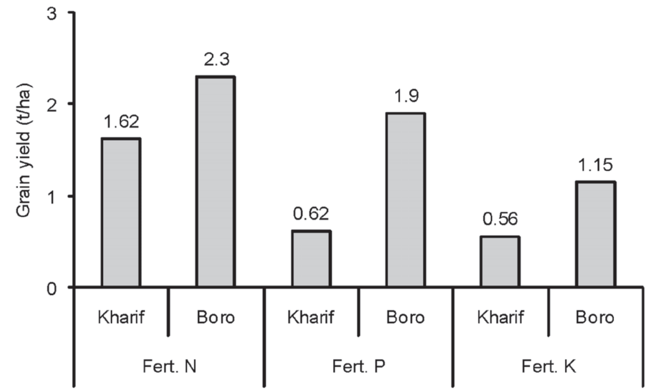


**Fig. 1.** Yield responses to fertilizer (Fert. N, Fertilizer nitrogen; Fert. P, Fertilizer phosphorus; Fert. K, Fertilizer potassium) while the yield target was 4.90 and 5.10 t/ha in *kharif* and *boro* season, respectively achieved with $SSNM_{NE}$ [values are mean of 2 years]

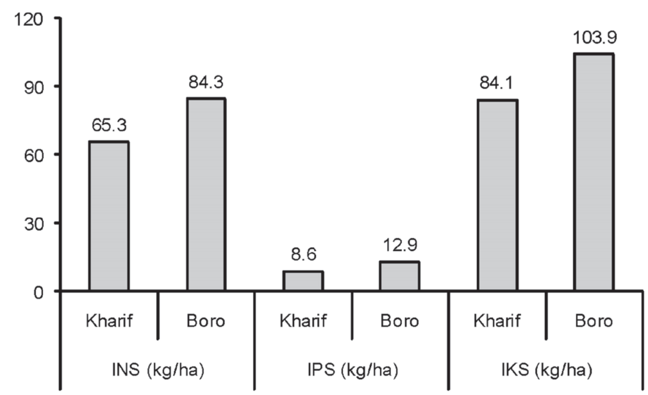


**Fig. 2.** Indigenous nutrient supply (INS, Indigenous nitrogen supply; IPS, Indigenous phosphorus supply; IKS, Indigenous potassium supply) in *kharif* and *boro* season at the study site [values are mean of 2 years]

### *Nutrient uptake in rice*

Total N, P and K uptake was significantly higher when the tested cultivar grown with $SSNM_{NE}$ treatment (14.11, 28.67 and 11.10% more than the values obtained in FFP treatment respectively in *kharif* season; while 13.11, 23.16 and 13.02% more than the values obtained in FFP treatment respectively in *boro* season) (Table 5). Similar observations were reported by Pal *et al.* (2008) who demonstrated higher nutrient uptake with increased and balanced fertilizer application. Garai *et al.* (2020) also claimed that the synchronization of fertilizer application time with crop demand with the help of NE®, LCC etc. leads to better utilization of nutrients by the crop. In the current study, both $SSNM_{NE}$ and $SSNM_{LCC}$ treatments assured need-based NPK supply to rice crops, which might have resulted higher NUE. Such results again proved the fact that, the precision agricultural tools like SSNM, LCC etc. facilitate low-input demand with maximum efficiency (Banerjee *et al.,* 2019). In the present study, N omission ($SSNM_{NE}$ – N) treatment caused maximum reduction in total N, P and K uptake (45.81, 64.67 and 20.17% less than the values obtained in $SSNM_{NE}$ treatment respectively in *kharif* season; while 40.04, 54.7 and 20.44% less than the values obtained in $SSNM_{NE}$ treatment respectively in *boro* season). Poor N, P and K uptake were recorded in plots under NPK omission (absolute control treatment).

### *Available nutrient status in post-harvest soil*

The status of available N, P and K in post-harvest soil was significantly influenced by different fertilizer levels (Table 5). The P omission treatment ($SSNM_{NE}$ – P) showed significantly higher available N content over other treatments (16.79 and 12.67% more than the values obtained in FFP treatment during *kharif* and *boro* season respectively). Soils in FFP plots had significantly higher available P content in both seasons. But soils in N-omitted plots ($SSNM_{NE}$ – N) showed significantly higher available K content over other treatments (44.60 and 31.15% more than the values obtained in FFP treatment during *kharif* and *boro* season, respectively). Poor balance of potassium in K-omitted plots might be attributed to the known fact that plants take up excess potassium above its normal requirement (Mitra *et al.,* 2019). Despite of providing fertilizer NPK to rice crops using NE® and LCC tools in the current study, there was a considerable amount of nutrient build-up in post-harvest soil. This result again proved the fact that, a large part of chemical fertilizers is not utilized by the crop plants and may

**Table 5.** Total nutrient uptake in rice (cv. Satabdi) and available nutrient status in post-harvest soil under different treatments (mean data of *Kharif* 2019 and 2020, and *Boro* 2019–20 and 2020–21)

| Treatment | Total nutrient uptake (kg/ha) | | | | | | Available nutrient (kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | | P | | K | | N | | P | | K | |
| | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* | *Kharif* | *Boro* |
| $T_1$, RDF | 119.2 | 131.3 | 15.6 | 20.3 | 103.4 | 120.6 | 139.5 | 162.8 | 24.3 | 43.2 | 56.1 | 71.7 |
| $T_2$, $SSNM_{NE}$ | 120.5 | 140.6 | 18.4 | 23.4 | 105.1 | 126.7 | 141.6 | 162.2 | 16.5 | 30.8 | 54.3 | 70.7 |
| $T_3$, $SSNM_{LCC}$ | 108.9 | 124.1 | 16.0 | 20.4 | 98.3 | 115.3 | 145.3 | 162.0 | 15.8 | 31.5 | 63.8 | 81.4 |
| $T_4$, $SSNM_{NE}$ – N | 65.3 | 84.3 | 6.5 | 10.6 | 83.9 | 100.8 | 93.7 | 111.0 | 20.6 | 39.7 | 73.6 | 92.2 |
| $T_5$, $SSNM_{NE}$ – P | 75.9 | 95.7 | 8.6 | 12.9 | 88.7 | 107.1 | 180.2 | 201.8 | 15.9 | 3.1 | 70.1 | 89.2 |
| $T_6$, $SSNM_{NE}$ – K | 101.7 | 121.0 | 14.0 | 18.1 | 84.1 | 103.9 | 150.1 | 174.0 | 19.7 | 34.2 | 28.0 | 33.9 |
| $T_7$, AC (–NPK) | 40.6 | 59.4 | 4.7 | 7.7 | 65.8 | 79.7 | 99.6 | 116.7 | 17.0 | 8.0 | 34.6 | 53.7 |
| $T_8$, FFP | 105.6 | 124.3 | 14.3 | 19.0 | 94.6 | 112.1 | 154.3 | 179.1 | 25.6 | 43.2 | 50.9 | 70.3 |
| SEm± | 1.3 | 1.5 | 0.2 | 0.3 | 0.6 | 0.7 | 2.9 | 3.2 | 1.0 | 1.2 | 1.3 | 1.4 |
| CD (P= 0.05) | 3.8 | 4.5 | 0.6 | 0.9 | 1.8 | 2.3 | 8.9 | 9.8 | 3.1 | 3.8 | 3.9 | 4.5 |

RDF, recommended dose of fertilizers; $SSNM_{NE}$, SSNM based on 'Nutrient Expert' recommendation; $SSNM_{LCC}$, SSNM based on leaf colour chart; AC, absolute control; FFP, farmer's fertilizer practice
N, nitrogen; P, phosphorus; K, potassium
NS, non-significance at 0.05%

cause a significant contribution to environmental pollution if blanket dose is followed (Banerjee *et al.,* 2019).

### *Economic benefits and system economic efficiency of rice-rice cropping system*

Application of $SSNM_{NE}$ treatment resulted in the highest net returns (Rs. 22247 and Rs. 49053/ha in *kharif* and *boro* season, respectively) and benefit: cost ratio (2.48 and 1.95 in *kharif* and *boro* season, respectively) among all fertilization practices (Table 4). System economic efficiency of rice-rice cropping system was also highest in $SSNM_{NE}$ treatment. The next best treatment was $SSNM_{LCC}$. However, further addition of NPK (RDF) resulted in decrease on net return and B:C ratio. These results are in partial agreement with the findings of Pal *et al.* (2008), who reported that net returns and B:C ratio were relatively low in FFP treatment and high in balanced fertilization practice. Thus, it shows that nutrient rationalization techniques in SSNM strategies contribute to better economics for the farmer over the existing approaches of crop fertilization (Mitra *et al.,* 2019). Across the Asian countries, it has been well reported that the SSNM approach significantly improves the farmers economic return from on-farm trials since last 20 years (Garai *et al.,* 2021). Banerjee *et al.* (2019) also claimed that SSNM helps farmers to achieve maximum profit where cost of fertilizer input per unit of production is lowered. In the present study, the poor response in net returns and B:C ratio was recorded in crops under NPK omission treatment (absolute control).

Thus, it can be inferred that the SSNM approach may break the yield barrier of rice by enhancing the yield components through judicious exploitation of the available nutrients. The 'Nutrient Expert' software-based solution, recommending 50-14-21 and 125-39-65 kg N-$P_2O_5$-$K_2O$/ha in *kharif* and *boro* season, respectively proved to be the most beneficial intervention towards yield and economic gain in rice-rice cropping system. The leaf color chart (LCC) based nutrient rationing 50-14-21 and 112-39-65 kg N-$P_2O_5$-$K_2O$/ha in *kharif* and *boro* season respectively also gave satisfactory performance. Balanced nutrition in both the above treatments would lead to higher nutrient quality of crops and better environmental protection. Summarizing all, Nutrient Expert® and LCC may be considered as an effective nutrient management tool for profitable rice production, while ensuring environmental sustainability.

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